

# Diffusers for holographic stereography

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## Abstract

Holographic diffusers have long been recognized as versatile components with a broad number of applications. In this work we discuss holographic diffusers for projection of laser light from a Liquid Crystal Display(LCD) onto a holographic recording medium. In holographic stereography, projection of the information from a LCD onto a holographic recording medium has traditionally been done by a lens or a ground glass. It is suggested that the holographic diffusers can replace these elements and improve image quality and light economy.

## I. INTRODUCTION

Storage of data by means of holography has long been an active field of research. Usually, the storage must be done in coherent light. However, by the application of holographic stereography, this requirement can be relaxed. A holographic stereogram is created by optical multiplexing of a finite number of viewpoints onto different regions of a high resolution recording medium (see ref. [1,2] and references therein). The perspectives(or viewpoints) are usually displayed on a Liquid Crystal Display(LCD), and then projected onto a small area of the recording medium. Traditionally the multiplexing have been done in one of two ways [1,2]; 1)A cylindrical lens is placed behind a LCD, focusing the laser light into a small slit. This kind of holographic stereogram is usually referred to as a multiplex stereogram. The cylindrical lens conserve the image plane characteristics in the vertical direction, and gives rise to a rainbow colored 3D image [1]. Unfortunately, the intensity distribution at the focal plane of the cylindrical lens usually contains large variations due to diffraction. Unless the recording media has large dynamic range, these intensity variations gives rise to saturation and loss of information [2]. 2)The alternative is to produce a so-called DeBitetto stereogram [2,3]. In this case an ordinary diffuser is placed right behind the LCD, and diffuses the light in both the horizontal and vertical direction. Since the slit width is of order 1mm, most of the light from the diffuser is scattered outside the slit, giving very long exposure times. To reduce the exposure times, a ground glass with finite diffusing angle is applied. Unfortunately, this results in an uneven illuminated 3D image, especially when the ground glass is close to the holographic film. Note also that a ground glass will diffuse the light in the vertical direction as well, thus destroying the image plane characteristics. The DeBitetto stereogram is therefore not suitable for production of white light viewable transmission stereograms on thin emulsions. However, the image may be transferred to the plane of a second filmplate. Such image plane stereograms can be displayed in white light with very little color blur [2].

Ideally, the intensity distribution at the emulsion plane should be as rectangular as possible, it should contain equal contributions from all parts of the LCD(to obtain an even illuminated 3D image), and all the incoming light should be utilized. Furthermore, if the stereogram is recorded on a thin silver halide emulsion, the image plane characteristics must be preserved, to suppress cross-talk images [2]. None of the traditional techniques fulfill all these requirements. Therefore, alternative solutions must be found.

Pseudorandom diffusers seems to be a mature solution for both volume data storage and holographic stereograms [4–6], due to their ability to distribute the light at the focal plane, without destroying the image plane characteristics. Pseudorandom diffusers were introduced in holographic stereography by Klug *et al* [2], and independently by Yamaguchi *et al* [5], and were shown to increase the image quality of the holographic stereograms.

In this paper we propose two different holographic diffusers. The first type, which we will simply call a 'holographic diffuser', can be considered as an alternative to the classical diffuser in a DeBitetto stereogram. It is capable of directing more light into the slit in the holoprinter, and perhaps also improve the image quality, by providing a more even illuminated image than that resulting from a ground glass. The second type, which we will call a 'multiple-point holographic diffuser', can be considered as an alternative to the cylindrical lens in a multiplex stereograms. We think it is capable of improving the image

quality of multiplex stereograms, without significant reduction of the intensity incident on the recording medium. To confirm the quality of the holographic diffusers described above, we recorded a few holographic stereograms with the setup shown in fig. 6, which will be described later. This system will be referred to as the holoprinter. We would like to point out that the diffusers should be designed according to standard stereographic projection relationships, to ensure that the final images are free of anamorphic distortions(see e.g. [1–3] and references therein).

## II. HOLOGRAPHIC DIFFUSER

As mentioned in the previous section, application of a ground glass results in loss of light and uneven illumination of the different parts of the 3D image. A solution to this problem may be holographic diffusers. Holographic diffusers have been developed for many display purposes [7]. They are superior to classical diffusers in that they can redirect and control up to 100% of the incoming light. A holographic diffuser suitable for holographic stereography can be created as follows: 1)First a strip diffuser is created by covering an isotropic diffuser with a slit. 2)Next a hologram is recorded with this strip diffuser as the object. A hologram recorded in this way will simply be called a *holographic diffuser*.

To use this holographic diffuser in the production of a holographic stereogram, it must be placed in contact with the LCD screen. As pointed out in the introduction, the purpose of the LCD is to provide a perspective picture which can be projected onto a small area of the holographic film. By illuminating the LCD(+holographic diffuser) with a proper reconstruction beam, the real image of the strip diffuser is projected into the slit of the holoprinter. We believe that the real image of the slit should match that of the holoprinter since this ensures that the whole perspective picture is passed through the slit in the holoprinter, and that maximum amount of light is utilized. If the slit width of the holographic difuser is too small, we probably get picket fence artifacts(a detailed description of this problem is given in ref. [2]). If it is too big, some of the perspective picture is cut off, and there is also some loss of light.

To produce a holographic diffuser using the principles described above, we covered a diffuser(opal diffuser) with a 0.5mm slit. This strip diffuser was placed slightly away from focus of a cylindrical lens, see fig. 1. The lens was introduced to increase the amount of light passing through the strip diffuser, without introducing too large speckles. Since the lens was placed in front of the diffuser, its quality was not important. A collimated reference beam was illuminating the film at an angle of  $\sim 50^\circ$ , and the distance between the diffuser and the holographic films was approximately 30cm. With this setup we recorded a hologram with a 20mW HeNe laser on BB640 thin silver halide emulsions from HRT technologies. The size of the exposed film was  $12.7 \times 10$ cm, and we used a collimated reference beam which was larger than the film(and therefore considered uniform). The film was processed by a procedure similar to that suggested by Belendez et.al. [8], resulting in Silver Halide Sensitized Gelatin(SHSG). In this way we were able to produce a holographic diffuser with little unwanted scattering and 40% diffraction efficiency. During reconstruction, the real image will form a rectangular strip of 0.5mm width. We found that the effective(actual) size of the diffuser was  $10 \times 10$ cm(the holographic film was partially screened by the holder). Since the distance between the original strip diffuser and the holographic film was 30cm,

this results in a convergence angle of approximately  $\sim 9.5^\circ$  during reconstruction.

### III. MULTIPLE-POINT HOLOGRAPHIC DIFFUSER

In many applications we are interested in conserving the image plane characteristics in the vertical direction, to be able to display the (thin emulsion) stereogram in white light [1]. An optical element which does this can also be created by application of holographic principles. The experimental procedure is illustrated in fig. 2. We recorded a DeBitetto stereogram of a rectangular 'point' diffuser. The 'point' was a Edmund Opal diffuser of size  $1\text{mm} \times 1.2\text{mm}$ . 120 element holograms were recorded on  $12.7 \times 10\text{cm}$  BB520 with a 50 mW 532 nm  $Nd : YVO_4$  laser. The BB520 film was translated by 0.9mm between each exposure, equal to the width of the the slit covering the filmplate. The distance between the 'point' diffuser and the holographic film was approximately 30cm. The effective size of the diffuser was found to be  $10.8 \times 9\text{cm}$ , which results in a convergence angle of approximately  $\sim 8.5^\circ$  during reconstruction. A reference beam illuminated the film from above with an angle  $\sim 50^\circ$ . This reference beam could be considered uniform, since it was much larger than the rectangular slit in the holoprinter. The BB520-film was processed by a procedure similar to that suggested by Belendez et.al. [8], resulting in Silver Halide Sensitized Gelatin(SHSG). In this way we were able to produce a diffuser with little unwanted scattering and 30% diffraction efficiency. When the real image of this multiple element hologram was reconstructed, the diffuse points were reconstructed side by side, thus creating a vertical line, see fig. 2. We will name this kind of hologram a *multiple – point holographic diffuser*, since it acts differently from the holographic diffuser discussed in the previous section, and is supposed to be used during production of a multiplex stereogram. By illuminating the LCD(+ multiple-point holographic diffuser), the perspective information on the LCD is projected onto a line of size  $\sim 1.2\text{mm}$ . The line looks continous, since the width of each point(1mm) is slightly larger than the distance translated between each exposure(0.9mm). This gives a small overlap between reconstructed 'points'. Unfortunately, we have not conducted any analysis to see how this overlap influences the image quality. More research is needed to find out how this as well as the size of the slit influences the final image.

### IV. MEASUREMENTS OF THE INTENSITY DISTRIBUTIONS

We have measured the intensity distributions from the two holographic diffusers described above. The experimental setup used is shown in fig. 3. A detector from Pasco Scientific(model 8020) was covered with a small vertical slit of size  $10\mu\text{m}$ . The detector can be moved(longitudinally) to the proper 'focal' plane of the diffuser by a micrometer screw. A second micrometer screw was used to move the detector(transversally) across the intensity distribution in steps of  $10\mu\text{m}$ . The inaccuracy of the translating mechanism is about  $5\mu\text{m}$ . The same collimating lens was used during recording and reconstruction, and the collimated reference beam was larger than the exposed film( $12.7 \times 10\text{cm}$ ), and therefore considered uniform. The detector was placed at the point were the real image was supposed to be located. In both cases this distance was 30cm(as indicated in the descriptions above).

By translating the detector along the optical axis, we measured the highest possible peak intensity 30cm from the diffusers within an accuracy of  $\pm 1\text{cm}$ .

Fig. 4 shows the relative intensity distribution of the holographic diffuser. The width of the distribution is 0.5mm, which is the same as the width of the strip diffuser used to record the holographic diffuser. Some light is distributed outside the original boundaries, which may be caused by diffraction from the edge, unwanted scattering, or misalignment during reconstruction. The intensity variations within the passband is about 0.3. A major contributor to the rapid intensity variations is speckle noise introduced by the ground glass, but the emulsion will also contribute. Note also that the intensity distribution is not completely symmetric. We believe this is due to a slight misalignment of the slit during recording. In fig. 5, the intensity distribution at the 'focal' point of the multiple-point diffuser is shown. Note that the measured intensity distribution from the multiple-point diffuser is nearly rectangular. Again, some light is distributed outside the boundaries of the original 'point' diffuser (width 1.2mm). It is seen that the intensity variations within the passband is about 0.5. Furthermore, the variations are much more rapid than in fig. 4. This is believed to be due to the fact that we used different emulsions (BB520 and BB640), although this has not been completely clarified.

## V. SETUP FOR RECORDING HOLOGRAPHIC STEREOGRAMS

To confirm the quality of the holographic diffusers described above, we recorded a few holographic stereograms with the setup shown in fig. 6. The laser is a 20mW 632nm HeNe laser or a 50mW 532nm  $Nd : YVO_4$ -laser. The reference and object beams are separated by a beamsplitter, and then transported to different levels. The object beam is cleaned and expanded by a spatial filter, after which it illuminates the LCD. The LCD is placed in close contact with the diffuser, which directs the light into the slit of the printer. The reference beam is also cleaned and expanded, and then directed towards the slit in the printer. Each perspective picture on the LCD is exposed onto a strip of the holographic film, one by one. In total, a holographic stereogram is generated. We applied both the holographic and multiple-point diffusers in front of the LCD, with good results. We hope to publish a more detailed evaluation of the holographic stereograms produced with this holoprinter in a separate paper.

In conclusion, we have described two different diffusers which may be of interest in holographic stereography. We have performed some simple measurements to get a better picture of the performance of these diffusers. However, many questions are still not answered, and should be the subject of future investigations. In particular it would be interesting to see the influence of different numerical apertures, the reference beam angle, the polarization of the incident beam, and the size of the slit. Also the influence of overlap in the multiple-point diffuser should be studied in more detail.

This work was done while L. E. Helseth was at the University of Bergen.

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## FIGURES

FIG. 1. Recording and reconstruction of the holographic diffuser described in the text. An ordinary diffuser is covered by a small slit, and is illuminated from behind. The diffused light interfere with the reference beam at the filmplane. When reconstructed, the real image is a strip of the same size as the original strip diffuser.

FIG. 2. Recording and reconstruction of the multippel-point holographic diffuser described in the text. The light from a point diffuser is applied as object beam. Between each exposure the film is transported a distance  $s$ .

FIG. 3. Setup for measuring the intensity distributions. A detector is covered by a  $10\mu m$  slit. During measurement, the detector is translated in steps of  $10\mu m$ .

FIG. 4. Intensity distribution from the holographic diffuser. The diffuser is recorded on BB640, and reconstructed with a 20mW  $632nm$  HeNe laser.

FIG. 5. Intensity distribution from the multippel-point holographic diffuser. It was recorded on BB520, and reconstructed with a 50mW  $Nd : YVO_4$  laser.

FIG. 6. Setup for recording a holographic stereogram with a holographic diffuser or multiple-point holographic diffuser. The dashed line represents the beampath on the second level. The reference beam illuminate the filmplate from above.

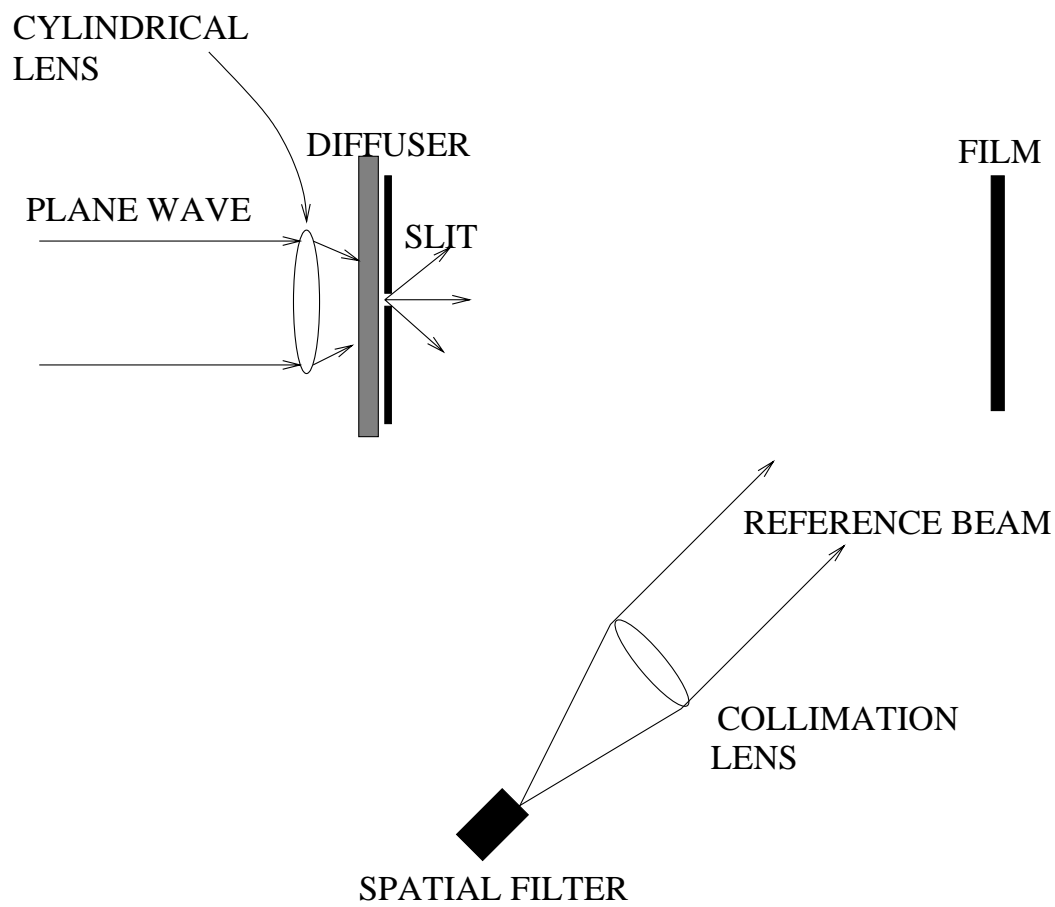


Figure 1



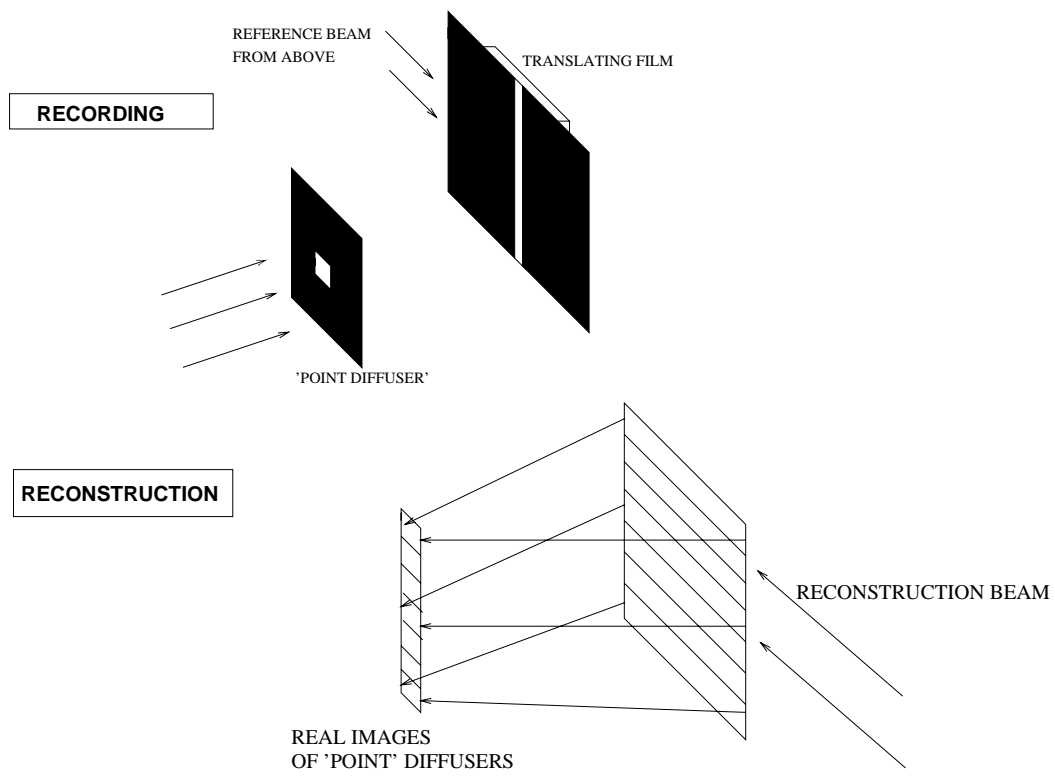


Figure 2

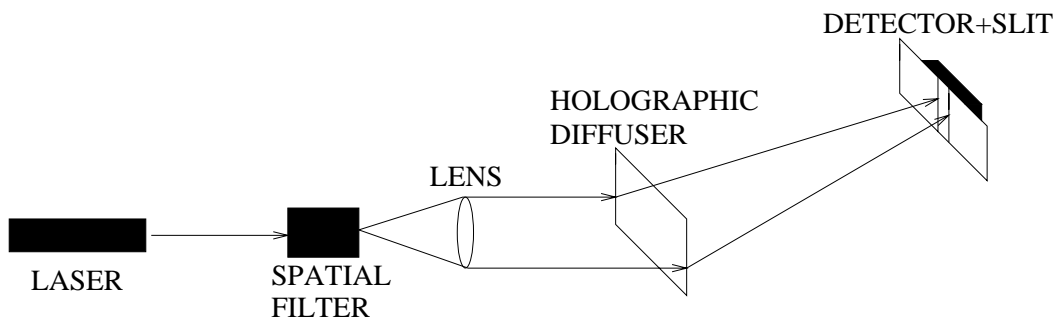


Figure 3

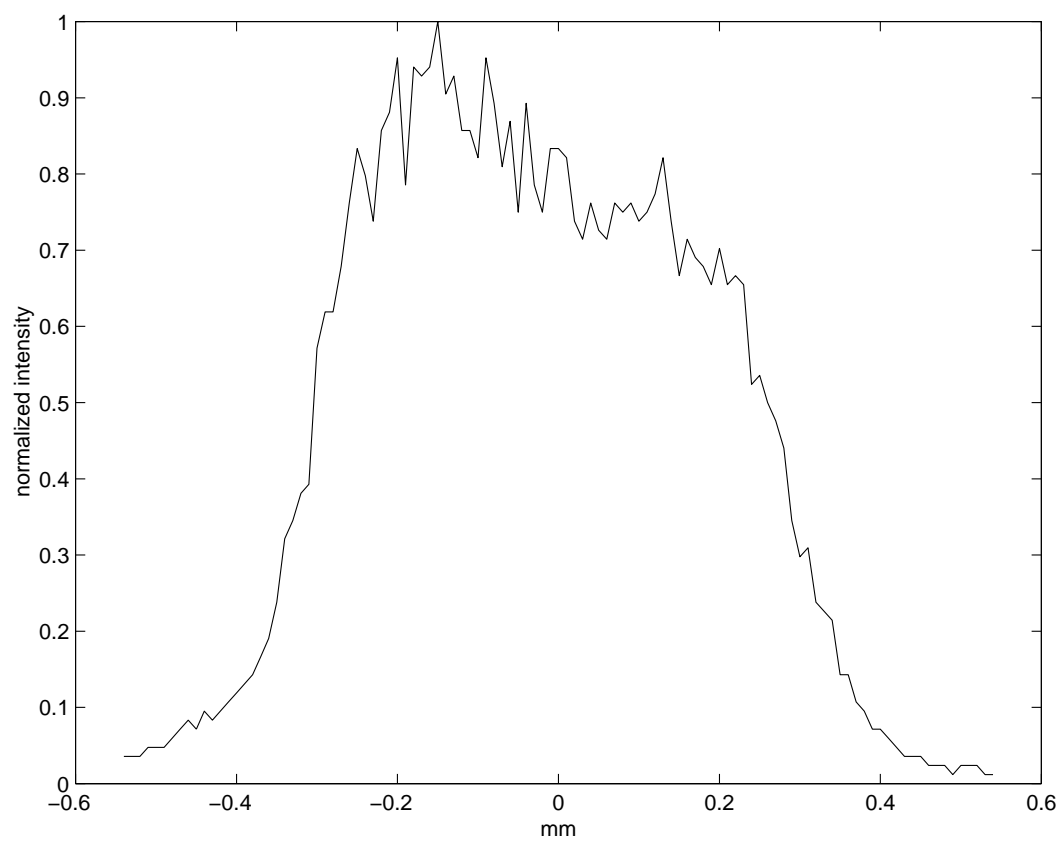


Figure 4

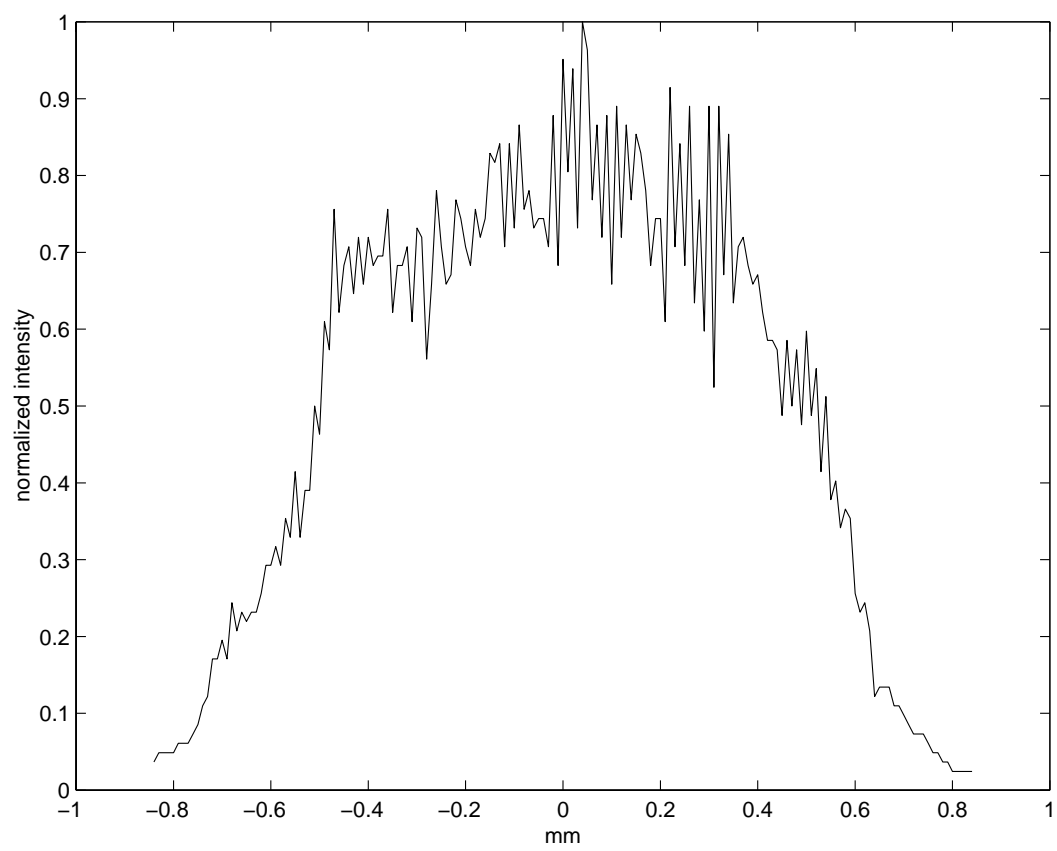


Figure 5

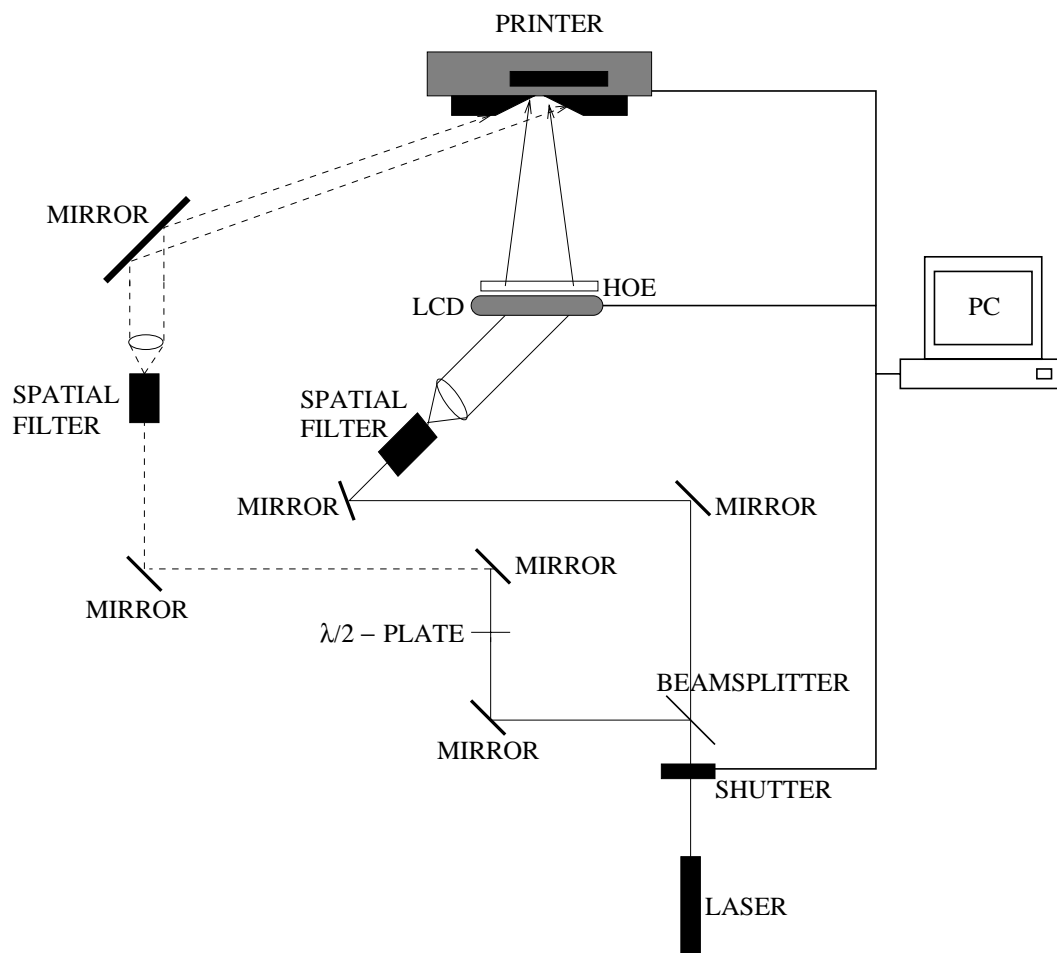


Figure 6